# Research Based on the Numerical Analytical Method for Hot Stamping of Titanium Alloy Sheet Metal with Springback Compensation

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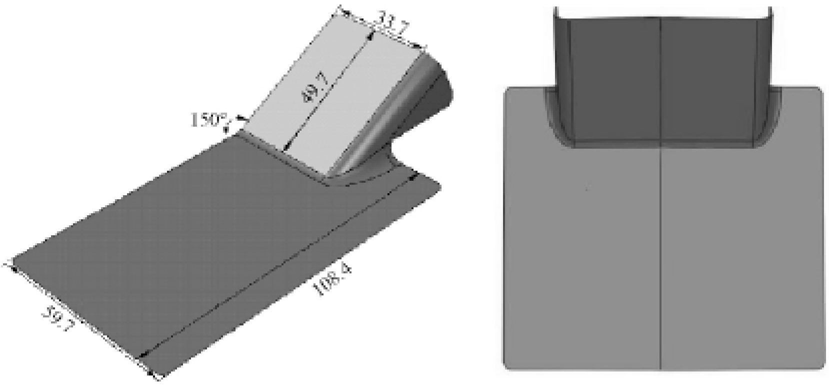
**Abstract:** the Hot-Formed Surface Rebound Parts of Titanium Alloy is a Problem to Be Solved in the Formation of Titanium Alloy Sheets. So in This Paper, the Titanium Alloy Bending Parts, and the Numerical Analysis Method is Used to Determine the Size of the Profile Before the Part is Rebounds. Based on This Design, the Hot Forming Mold with the Springback Compensation is Designed, and the Test Process is Combined with the Optimization Forming Process Parameters Which is to Control the Shape Accuracy of the Hot Forming Process of the Titanium Alloy Parts in Order to Achieve Accurate Forming of the Parts.

## 1. Introduction

Titanium alloys have relatively low density, corrosion resistance, high specific strength, weldability, and has good medium temperature performance, they are widely used in aerospace, aviation, weapons and ships, and they are important metal materials. The Titanium plate parts formed by titanium alloy sheets are widely used in the aerospace industry, especially in an advanced aero engines, and have the tendency to increase the structural integration and reduces the weight of the transmitter, it also plays an important role in improving the engine performance [1]. Based on the stamping forming technology which is to realize the manufacture of the titanium plate parts as the main content in the process of titanium engineering, so this paper realizes the numerical analysis of the hot stamping of titanium alloy sheet with the springback compensation.

## 2. Part Process Analysis

The three-dimensional structure of the sheet metal support is shown in Figure 1(a), and the material is TC4 titanium alloy with a wall thickness of 1.02mm. The shape of the upper part is more complicated so that it has higher precision requirements for the size, while the lower part is designed in a plane part, and the stamping is realized by a special mold. Then, the balance of the forming force is emphasized, and the forming efficiency is further improved, the forming mold which is designed as two molds, and the cutting allowance is left in the middle, which is symmetrical. See Figure 1(b) for details.



(a)three-dimensional structure (b) mold

Figure 1 Three-Dimensional Structure of the Part and a Two-Piece Arrangement

## 3. Mold Design

### 3.1 The Design of the Main Profile

The material parts of the hot forming process is fully pressed in the mold, at this time, the part is the same as the mold surface, not only the calculation of the profile before the rebound, but also the determination of the mold profile [2]. Since the part profile has bending and sag in different directions, and the part blank is formed based on high temperature, while the blank is lowered from the high temperature to normal temperature after forming, and rebounds in a temperature changing environment. During the forming process, the material undergoes some changes such as grain boundary diffusion, viscous flow and slip, and gradually releases the initial stress. In addition, the hardening coefficient and elastic modulus of the material during the pressure holding and forming process will change. Therefore, it is difficult to calculate the bending radius before rebounding, but in order to be able to be simplified the part which is approximated to a normal temperature unidirectional bending rate [3], the equation of the deformation process is:

$$\sigma = K\varepsilon^{\bar{\varepsilon}m}$$

Where n refers to the strain hardening coefficient of the material and m refers to the strain rate sensitivity coefficient, and this formula can also be written as:

$$\sigma = K\varepsilon^{n} \quad \text{Then} \; K = \sigma / \varepsilon^{n}$$

The bending forming angle rebound equation at normal temperature is:

$$SB_0 = \frac{3K}{(n+2)E} * \left(\frac{h}{2\rho_0}\right)^{n-1}$$

Where h refers to the material thickness, refers to the radius of curvature of the neutral layer, ET refers to the material based on the forming temperature elastic modulus, nT refers to the strain hardening coefficient, KT refers to the tensile bending coefficient, refers to the strain , refers to the tensile strength at the forming temperature.

With the above equations and known physical quantities, the main profile and area radius values of the mold before rebound can be obtained:

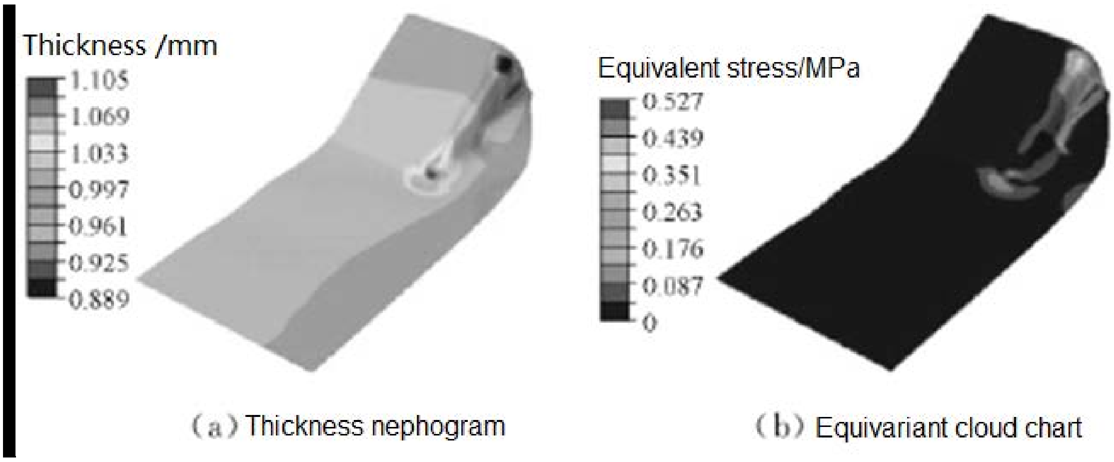
$$L_{(弧长)} = \theta \bullet R = (\theta + \Delta\theta)_T \bullet R'$$

$$R' = \theta \bullet R = (\theta + \Delta\theta)$$

### 3.2 Implementing the Inverse Algorithm

Figure 2 shows the simulation results of the rectangular blank. It can be seen from Figure 2 that because of the large degree of deformation, there is a risk of rupture at the top of the 90° angle of the simulated forming, which hinders the metal flow at the starting end of the part protrusion, and a large accumulation of metal occurs. , leading to the emergence of a wrinkled danger zone. In addition, the obvious wrinkles are raised places. Because the geometrical shape of the protrusions of the brackets is complicated, the use of the empirical method and the rectangular blank with the notched rectangular material will result in concentrated deformation and uneven stress distribution, resulting in poor quality of the surface of the parts. And increased processing difficulty, resulting in wasting a lot of materials and reducing resource utilization [4].

In order to reduce material waste, the blank forming design is realized by numerical analysis method according to the size and shape of the bracket member. The simplification of the sheet metal forming process is a simple loading. The full-scale theory ignores the change of the intermediate configuration, and the initial and final configurations are comprehensively considered, and the condition of the blank of the formed part is predicted.



(a) Cloud thickness (b) Equivalent strain cloud

Figure 2 The Result of Rectangular Blank Simulation

### 3.3 Optimization of Blank Simulation Results

Figure 3 is a simulation of the optimized forming part, where the wall thickness is gradually reduced at the stress concentration in the opening. There is material accumulation in the convex deformation area of the plate, and the rectangular sheet material is not wrinkled, which reduces the dangerous area of cracking and wrinkling. According to the equivalent stress, the internal stress of the opening is the largest, and the stress on both sides is gradually reduced. The 90° corner of the protruding portion of the part has a large amount of deformation and stress, and the effect of forming and plasticity is good.

Figure 3 Optimized Molded Part Simulation

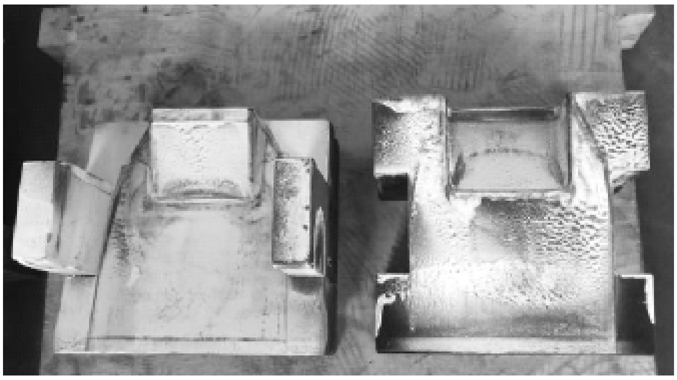


Figure 4 Mold

### 3.4 Mold Design

In order to solve the problem of difficulty in forming titanium alloy, the mold is designed by special hot forming equipment through the process of forming the heat of the sheet and the mold in the same temperature, and the part is shaped by the action of the mold based on the punching force of the equipment. Taking the characteristics of the part and the one-piece two-piece forming method, the problem of the difference in the expansion coefficient of the titanium alloy and the mold material is comprehensively considered, thereby realizing the design of the mold size. Apply heat-resistant medium-molybdenum spheroidal graphite cast iron to the mold material, and set the mold expansion coefficient to 0.997 [5]. Figure 4 shows the mold.

Simulation of 3 titanium alloy sheet metal hot forming

The analysis method of this paper is carried out to realize a large number of numerical simulation research of parts, predict and verify the stamping forming results, solve the quality problems in the stamping forming process, and propose the modification of the process plan and the mold according to the results of numerical simulation analysis. In order to fully grasp the authenticity of the numerical simulation of stamping, it is first necessary to grasp the performance parameters of the forming of the titanium alloy material of this part. The molding property parameters generally used are Poisson's ratio, Young's modulus, hardening index, trend stress, and the like. The way to obtain sheet formability is mainly provided by experimental testing and sheet suppliers.

Figure 5 Shows a Titanium Alloy Part with a Plate Thickness of 1.5 Mm and the Thinnest Part of the Part after Thermoforming Exceeds 1 Mm.

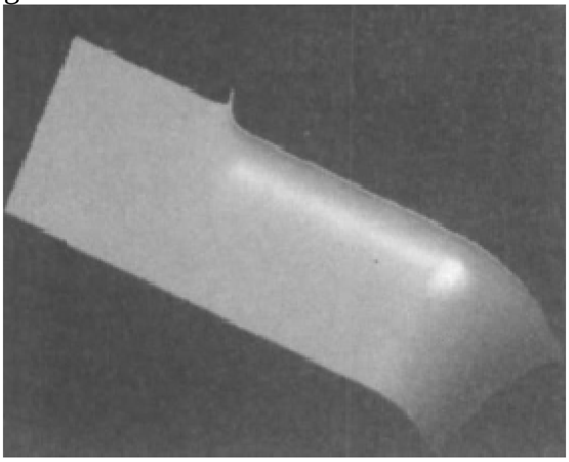


Figure 5 Titanium Alloy Parts

The basic performance parameters of the material at 550 °C were obtained by experiments. The Poisson's ratio was 0.41, the Young's modulus was 4.5*104Pa, the hardening index was 2, and the friction coefficient was 0.15.

The mold part and sheet geometry are created by CATIA, and the pre-processing is realized by IGS interface reading. Figure 6 shows the part thickness distribution map, and the blank holder force is set to 180kN. The mold has a total of 10,138 finite element units and 11,829 sheet units.

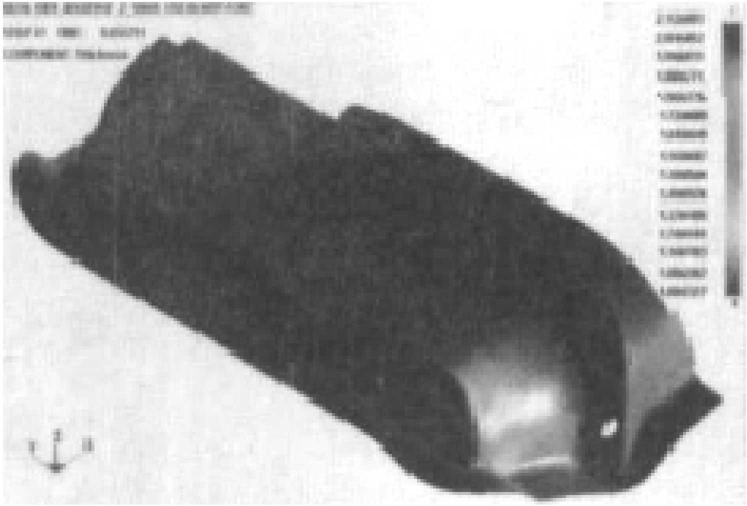


Figure 6 Part Thickness Distribution

As can be seen from the simulation results, the thickness of the titanium plate after hot stamping is 1.10 mm - 1.70 mm, that is, the thickness of the thinnest part is 1.10 mm. Because this titanium alloy part has severe cracking and wrinkling in the previous mold production process, the thickness of the part is required to be more than 1.0 mm after molding, and the current mold has reached this quality requirement in the current process conditions, so it can be put into use. Formal production [6].

## 4. Conclusion

The use of a spring-loaded thermoforming mold with springback compensation enables the precision of the profile after bending-type thermoforming to achieve a precise shaping of the curved titanium alloy parts. In the range of a suitable titanium, the alloy thermoforming parameters, which are the forming pressure and preheating temperature that have little effect on the springback, and the forming temperature holding time will affect the rebound, the forming temperature which has the greatest impact on the rebound also the complex analysis method is used to determine the bending radius of the mold before rebound, so it is necessary to use a plurality of the parameter performance when the material is hot, which limits the popularization of the calculation method.

## References

[1] Hu Dan. Research on precision forming technology of aircraft titanium alloy sheet metal rubber bag [D]. Nanjing University of Aeronautics and Astronautics, 2014.

[2] Hua Yuyu, Xu Xuefeng, Xiao Wei, et al. Experimental study on thermoforming of titanium alloy based on model features[J]. Special Casting & Nonferrous Alloys, 2018, 38(3): 323-326.

[3] Liu Qi, Li Baoyong, Qin Zhonghuan, et al. Hot Press Forming Process of TA15 Titanium Alloy Profiled Sheet Metal Parts [J]. Aerospace Manufacturing Technology, 2017(4).

[4] Zhang Lingyun, Wang Jun, Liu Huan, et al. Springback Compensation and Experimental Verification of Rubber Forming of 6061 Aluminum Alloy Curved Flanging Parts[J]. Forging & Stamping Technology, 2018, 43(2): 44-49.

[5] Yang Guang, Chen Shenglin, Shi Wenmin, et al. Study on the Rebound Quantity of Wound Cores by Experimental Method [J]. Journal of Wuhan Institute of Engineering Technology, 2016, 28(4): 19-23.

[6] Chen Haibing. Realization of elastic rebound compensation function of powder pressing based on hydraulic servo control[J]. Hydro-pneumatics and Sealing, 2018, 38(2).